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A PRELIMINARY STUDY OF HIGH-RATE COMPOSTING

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A PRELIMINARY STUDY OF HIGH-RATE COMPOSTING

John S. Wiley, A.M. ASCE,* and George W. Pearce*

SYNOPSIS

Six 15-gallon laboratory, batch-type, mechanical composters for determining the criteria for high-rate composting of organic wastes are described. The physical and chemical tests for indicating the degree of decomposition during the composting are outlined and typical results are presented. Optimum stirring and aeration rates as well as percentage of moisture in the initial charge are presented for the laboratory units. Correlation of carbon dioxide and moisture production with temperature of compost is shown and the respiratory quotient for the decomposition is given.

INTRODUCTION

Garbage and refuse treatment and disposal in the United States is woefully inadequate in most communities. The usual open dump is a public health hazard, an aesthetic nuisance, a space consumer, and is wasteful of badly needed organic matter. Often swine fed on raw garbage with devastating results as evidenced by widespread outbreaks of vesicular exanthema and by the less evident but important disease of humans, trichinosis. Burning the more readily combustible matter at a dump generally aggravates the aesthetic nuisance without eliminating any of the other hazards named. The next most popular method of refuse disposal, the sanitary landfill, will eliminate the health and nuisance hazards if properly operated, but still requires area and does not salvage organic matter for return to the soil. Incinerators are expensive to build and operate and also destroy the organic matter. Although they will eliminate disease hazards associated with refuse disposal, incinerators may increase the atmospheric pollution problem. If composting of garbage and refuse can be performed in mechanical units in a matter of a week or less, health and nuisance hazards should be eliminated and a worthwhile by-product provided.

Composting has been used with various organic wastes for many years in Europe, Asia and Africa. Generally, however, it is a slow process requiring 6 to 12 months under predominantly anaerobic conditions. Composting as tried by American cities in a few occasions has largely resulted in failure. Recently, there has been considerable interest in aerobic, thermophilic composting in windrows or outdoor piles. The University of California[1,2] has conducted some outstanding studies on bin and windrow composting, the first basic studies of the process in the United States. Additional studies on outdoor aerobic composting are being conducted by the Communicable Disease

* Dept. of Health, Education, and Welfare, Public Health Service, Communicable Disease Center, Technical Development Labs., Savannah, Ga.

Center at Phoenix, Arizona. Considerable activity also has been evidenced recently by several commercial groups and private individuals in aerobic, thermophilic composting in high rate mechanical units.[3,4,5,6,7] Little research has been conducted to evaluate these processes or the basic factors concerned with high-rate composting in mechanical units. Michigan State College has initiated studies along these lines[8] and the field offers much promise of producing a competitive method of treatment of refuse in a sanitary manner.

Studies at the Communicable Disease Center Laboratory at Savannah, Georgia, have as their objective the development of an economical method for converting organic wastes to usable by-products while eliminating the health hazards created by disease vectors and pathogenic organisms. House flies are often present as eggs or larvae in refuse reaching a dump and are attracted to and breed in exposed refuse. Rats and certain mosquito species, both of which may carry disease, are also problems in refuse disposal. Although pathogens may or may not be an important public health problem in the disposal of community solid wastes, certainly they are in sewage and sewage sludge disposal.

Well-composted matter, from innumerable sources of organic wastes of a community, may be of great value to the farmer, the home gardener, and the nursery man. Such matter contains humus so badly needed in certain clay or sandy soils. Compost may also be beneficial to the soil in many other ways: by retaining moisture which would otherwise run off or percolate, by checking excessive soil leaching, and by improving the general texture and physical condition of the soil.[9,10] Compost may be equal to or better than well-rotted stable manure when applied to the soil. Sale of such a by-product may serve to reduce the cost of refuse disposal so that composting may compete economically with even the less costly methods of disposal.

Description of Laboratory Composting Units

Preliminary tests were performed at Savannah in wooden boxes outdoors to determine the minimum size of units necessary to permit development of aerobic thermophilic organisms in ground refuse. While a unit of one cubic foot volume gave somewhat lower temperatures than larger units, it was apparent that temperatures above the lower limit for thermophilic action, 113° F (45° C), would be reached. Consequently, two units or drums one foot in diameter and one foot deep were constructed. These were provided with stirring mechanisms and one air inlet at the bottom. The drums were insulated, held approximately 18 pounds of refuse, and gave good compost in 4 to 11 days under optimum conditions. The central axis of one unit was vertical with stirring arms in a horizontal plane, while that of the other was horizontal with vertical stirring arms. Inasmuch as the former gave slightly but consistently better results, six identical larger units were constructed on the same principles. The multiple units were developed to permit a more rapid evaluation of the many variables of the process with the objective of determining the optimum conditions for rapid decomposition.

These units were constructed of 15-gallon stainless steel batch cans having a working capacity of about 11-gal. or 1.5 cu. ft. (figures 1 and 2). Two 1/2-inch diameter curved stirring arms are fastened to a 1-inch square vertical stirring shaft. The shaft extends through a top plate and is turned through a ratchet by means of an adjustable lever arm from a double-acting hydraulic cylinder. The cylinder piston is slowly pushed in its forward stroke by an

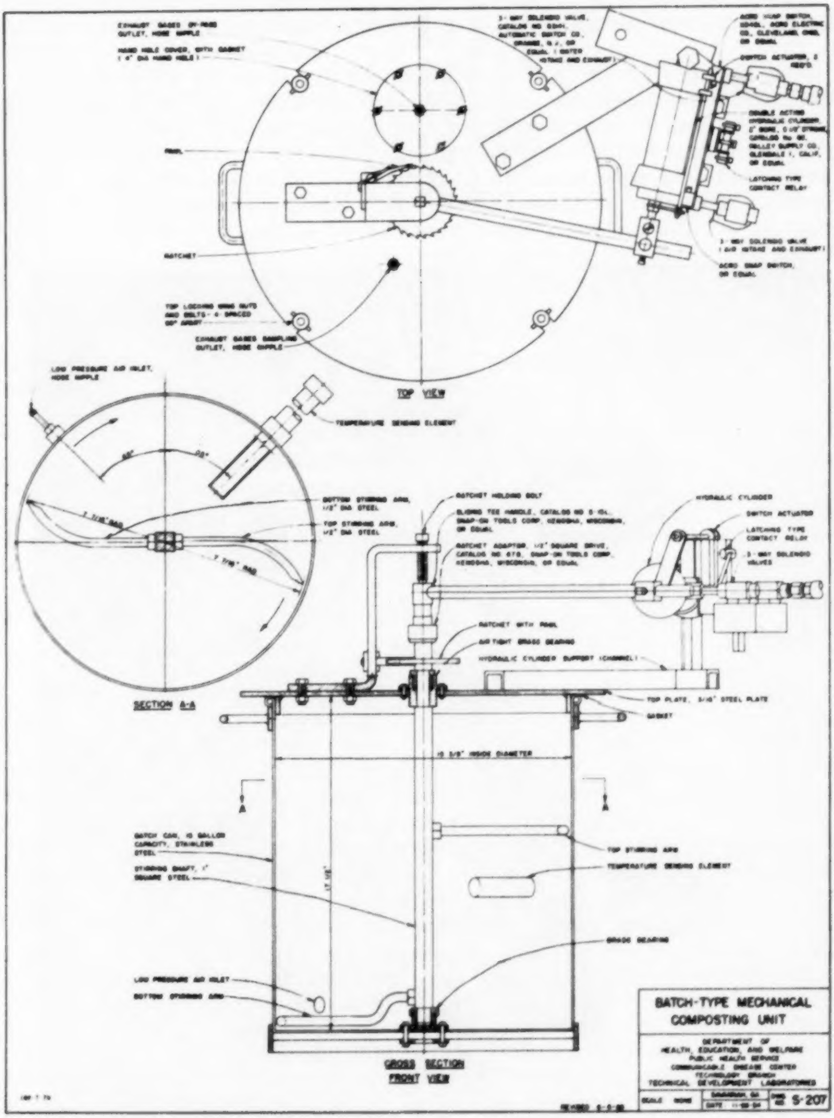

TOP VIEW
SECTION A-A
CROSS SECTION
FRONT VIEW
BATCH-TYPE MECHANICAL
COMPOSTING UNIT
S-207

Figure 1.

Fig. 2. Six laboratory composters in operation. The five pipe manifolds mounted on panel in rear are (top to bottom): low pressure air, hydraulic fluid, fluid return, high pressure air, waste gases.

emulsion of water and oil pumped at a pressure of about 75 psi. The return or nonoperating stroke is made by high pressure air, being accomplished rapidly (5 to 7 sec.) in order to simulate continuous stirring. Stirring rates are adjustable between 0.03 and 0.6 rpm by adjusting the lever arms on the units and the valves on the hydraulic fluid manifold. Three-way solenoid valves actuated by a latching-type contact relay control the liquid and air flows.

Low pressure air, 10 psi, is provided through a pressure reducing valve to a manifold and the amount of air needed for aerobic decomposition is regulated by inserting small orifices in the lines to each unit. A steel top plate, containing a 4-inch hand hole and plate, each provided with a gasket and thumb screws, make the units essentially airtight. Escaping gases pass through two hose nipples set in the top plates. By-pass and sampling orifices are placed in the two nipples to regulate the volume of gases going to samplers mounted immediately above each unit. Approximately one-twentieth of the air supplied to each drum is continuously passed through moisture and carbon dioxide absorption tubes.

Temperature sensing elements, connected to 3-pen, 24-hour recorders, are set 4 inches into the side of each drum at a height of 6-1/2 inches above the bottom.

In most of the experiments, the drums have been covered with two inches of cotton duct insulation to reduce heat losses. As all of the operating mechanism is mounted above the top of the drum, the drums may be placed in water baths for temperature control if desired. The raw materials which are ground, mixed, and sampled are charged through the 4-inch hand hole into the drums. Subsequent samples of the solid materials are removed through the hand hole. When a run is completed the entire top and stirring mechanism is removed so that the drum may be emptied and cleaned.

Raw Materials and Method of Procedure

After several unsuccessful attempts at composting wet garbage from a hospital and an Air Force Base, with and without the addition of dry materials such as paper, hay and leaves, it was decided to use mixed garbage and refuse from the City of Savannah disposal area. Savannah has a combined collection system which includes mixed refuse and garbage with the exception of leaves, grass clippings and tree limbs, which are collected separately. Refuse collections are made three times weekly from residential areas and average 4 to 5 times weekly from business establishments. Present disposal is by sanitary landfill for both household and yard refuse.

Fresh material for experimental composting is collected by opening paper sacks of garbage recently dumped by collection trucks, throwing out most of the non-compostable items, and depositing the remainder in 30-gallon cans. There is an excess of paper in the refuse, and moisture content of the material to be composted is adjusted by the amount of paper included. It is estimated that residential refuse from Savannah has a moisture content of about 30-35 per cent, including paper of all kinds amounting to over 50 per of the wet weight. Average results from the analysis of 18 batches of raw refuse used in the experiments were as follows (Jan. 21, 1954-April 12, 1955):

Moisture % (WW)	Volatile solids % (DW)	Carbon % (DW)	Nitrogen % (DW)	C/N	Protein (6.25N) % (DW)	pH
54.5	91.5	44.8	1.21	37	7.6	5.5

(WW) wet weight; (DW) dry weight

Sufficient raw refuse is brought to the laboratory area, where it is ground twice through a hammermill* provided with a roller screen. The first grind is with 1 7/8-inch and the second with 5/8-inch roller spacings. A predetermined amount is weighed out for each drum. For comparative runs, each drum receives the same total wet weight of raw refuse. Any additives, such as "starter," compost from a preceding run, chicken manure, fish scraps, concentrated sewage sludge, or lime, are also weighed on a pre-determined basis designed to give the desired percentage of additive on a dry weight basis. The exact moisture content of the initial mix is not known until one or two days of the run have elapsed. When it is desired to test the effect of various additives, each unit receives a calculated amount of distilled water so that all start with approximately the same percentage of moisture.

Compost from a preceding run has been generally used for seeding following some preliminary experiments with runs having no additives and with addition of a "starter" containing lime, lime alone, and "finished" compost. The "finished" compost is generally air dried and ground in the hammermill through a perforated screen with 1/4-inch holes.

Ingredients of a batch for one drum are thoroughly mixed and sampled before the drum is charged. Charging the six drums requires one to two hours by two men during which stirring mechanisms and aeration are in operation. This period of time is needed to permit the charge to settle in the drum and to add more refuse. Quantities used per drum depend on moisture content, but average about 36 pounds wet weight and 16 pounds dry weight. The volume of the charge is reduced rapidly the first day, and at the end of a run it is 1/2 to 2/3 of the original volume.

Several replicate runs were made initially with all factors alike for each drum. Interruptions of stirring occurred frequently with an occasional interruption of air flow. These cause marked changes in the temperature of the compost, especially if they occur on the second or third day, when peak values are about to be attained. Usually stirring speeds, aeration rates, and sampling rates are held as nearly alike as feasible throughout a run. Some initial attempts at "tapered" aeration did not seem to produce the desired results. Runs made to determine the optimum condition for a single variable are discussed later. Initially, there were many mechanical difficulties. Some of these were: failure of hydraulic fluid pump, inoperation or double operation of relays resulting in stoppage of stirring, leaking of 0-rings in cylinders resulting in stoppage or diminished rates of stirring, bending or breaking of stirring arms due to high torques, breaking of snap switches, power failure, and air compressor failure. Gradual improvements in design and operation have eliminated most of these difficulties.

As a general rule, stirring rates have been held between 0.10 and 0.16 rpm, variations between drums in a single run being less than $\pm$ 0.015 rpm. However, stirring rates are not critical, as will be shown later. Aeration rates ranged from 0.24 to 0.27 cfm per drum or 23-29 cu ft per day per lb volatile solids in the initial charge.

Limited trials with and without the layer of insulating material around each drum indicated slightly higher temperatures, greater moisture evaporation and production, and slightly less carbon dioxide production and volatile solids lost in the insulated drums. For the most part, all drums have been insulated. In one trial, drums receiving air for aeration at average temperatures of 98° F and 67.5° F showed no significant difference in temperatures of the

* Model 21, W-W Grinder Corp., Wichita, Kansas

composting materials, although a slightly greater loss in volatile solids occurred in the drum receiving heated air. No further experiments with external heat or cooling provided have been made, although there is some thought that cooling during peak activity may be necessary to prevent the desired microorganisms from being killed.

The end of a run is indicated when all or most drums return to within about 10° F of room temperature. At that time the entire top and stirring mechanism are removed,and the wet weight of the compost is obtained. Samples are analyzed so that the weights of the various components may be calculated and compared with the initial values. Except in runs in which aeration rates or moisture of the initial mixture have been varied, there is usually no drop in percentage moisture of the compost. The "finished" compost is adjusted to a suitable moisture content by partial air drying or by adding water when necessary, rapidly mixed and aerated, and placed in open cans for a re-heating test. There should be little subsequent heating if the course of composting has been good. However, it has recently been learned that so-called "finished" compost will re-heat, sometimes more than once, upon being dried, re-ground to smaller sizes, and reconstituted with water. Re-heating experiments are now being carried out two or three times including at least one drying and grinding operation.

Sampling and Testing Procedures

Duplicate samples are collected for moisture determinations,initially, every three days, and finally in covered metal dishes having a capacity of about 250 ml. Moisture is determined gravimetrically by drying in an oven at 102-105° C for about 48 hours. Drying periods as short as 24 hours were found to be insufficient for the size of samples used, 60-150 g. Some of the more readily volatilized compounds, such as volatile acids, carbonates, and ammonia, may be included as moisture in the oven-drying process. Moisture is reported as per cent of wet weight. After drying, the duplicate samples are ground in a laboratory mill through a perforated screen with 1 mm holes, the ground samples being stored in sealed jars.

A test for volatile solids(11) measures the amount of combustible matter or weight lost on ashing of a sample. For determination of volatile solids, duplicate samples of re-dried sample (generally 3 to 6 grams) are ashed at 650-700° C for at least two hours in a muffle furnace. Per cent volatile solids is computed on a dry weight basis. The volatile solids represent primarily organic matter in the compost,but may also include volatile minerals and carbon dioxide lost during ignition. Corrections for materials added to the refuse before or during composting have not been applied to the results reported. The addition of lime, starter, or compost from a previous run increases the ash content, thus decreasing the per cent volatile solids.

Carbon and nitrogen are also determined on the oven-dried and ground samples after re-drying at 102-105° C. Total carbon is determined by a semi-micro, wet combustion method.(12) Approximately 15 mg of the sample are used. Carbon is reported as per cent C on a dry weight basis.

Nitrogen, with the exception of nitrites and nitrates, is determined by a micro-Kjeldahl procedure using 10-15 mg of ground and re-dried sample. Nitrogen is reported as per cent N on a dry weight basis. Protein can be estimated by multiplying nitrogen by the factor 6.25. The carbon-nitrogen ratio is computed as per cent C/per cent N.

Samples of 5 to 10 g are collected daily for pH. They are diluted with

CO_2-free distilled water. Determination is made by means of a glass electrode pH meter after vigorous stirring.

The temperature of the composting material is continuously recorded, and records are also maintained of the ambient (room) temperature. Temperature of inlet air admitted to the drums varies less than 2° F from ambient.

Special samples may be removed from the drums whenever desired. Amounts removed due to all samplings, together with estimated losses or spills, are added to the final net weights of compost removed from the drums.

Carbon dioxide and moisture are the two major products of aerobic composting that are found in the outlet gases. Moisture collected from outlet gases is both from evaporation of free moisture in the composting mixture and the biological oxidation of organic matter. In order to obtain a stoichiometric balance between input and output of each drum, measured portions of the outlet air are sampled continuously for determination of H_2O and CO_2. Moisture is sampled in 18-inch by 1 1/4-inch diameter glass tubes containing indicating Drierite (8 mesh anhydrous $CaSO_4$). These tubes contain 300-350 g of Drierite capable of absorbing about 75 g of moisture. The indicator color changes from blue to pink as the Drierite absorbs water. The moisture is determined gravimetrically for the measured amount of air sampled and is then converted by calculation to that for the total 24-hour flow for each drum and expressed as lb per day per 100 lb of volatile solids (initial charge in each unit). Tubes are changed once per day, the sampling periods varying from 1,000 to 1,500 minutes. Drierite is regenerated by heating.

Carbon dioxide is absorbed similarly and determined gravimetrically following removal of moisture by the Drierite tubes. Ascarite (sodium hydroxide impregnated asbestos, 8 to 20 mesh) is used in 12-inch by 1 1/4-inch diameter glass tubes. These tubes contain 180-205 g of Ascarite capable of absorbing about 60 g of carbon dioxide. The Ascarite changes color from light brown to white as it absorbs CO_2. The CO_2 is also reported as lb per day per 100 lb volatile solids. Air sampling flows are measured with a wet test meter after the air has passed through the Drierite and Ascarite tubes. Total air flow to each drum is checked periodically with the wet test meter and has been found to be fairly constant.

A few special or non-routine tests have been performed on raw refuse and compost, including fly rearing; bacteriological plate counts of thermophilic bacteria, actinomycetes, and fungi; reducing sugars; and moisture determined by the Karl Fischer method.[13] However, more work needs to be done before these results are reported.

Although other by-products besides CO_2 and H_2O are given off atmospherically, such as volatile acids, occasionally ammonia, and perhaps many others, it is believed that the total is very small in relation to the total mass being composted. As a result, everything of significance on a total weight basis is being measured except the oxygen consumed in the oxidation process. The aerobic composting process might be represented thus:

$$\underbrace{C_pH_qO_rN_s \cdot {}_aH_2O + {}_bO_2}_{\text{Intake}} \longrightarrow \underbrace{C_tH_uO_vN_w \cdot {}_cH_2O + {}_dH_2O\uparrow + eH_2O\uparrow + fCO_2\uparrow}_{\text{Output}}$$

(Raw garbage) (O_2 used) (Finished compost) (H_2O evap.) (H_2O prod.) (CO_2 prod.)

Small letters represent constants for given conditions. If only the organic matter destroyed is considered, this equation is simplified to:

$$C_xH_yO_z \quad + \quad bO_2 \longrightarrow xCO_2\uparrow \quad + \quad y/2\ H_2O\uparrow$$

(Vol. solids lost) (O_2 used) (CO_2 produced) (H_2O produced)

The weight of oxygen may be obtained by difference as all other constituents are known. The respiratory quotient (R.Q.=vol CO_2/vol O_2) may be computed and checked against other aerobic decomposition process, such as the activated sludge process.(14)

Typical Composting Run

A typical garbage composting batch run is shown in figure 3 with curves for temperature and pH of compost and for H_2O and CO_2 produced and evaporated in the outlet gases. The temperature of the composting mass increases rapidly to 100-110° F in about 24 hours. At this point there is usually a reduction in the rate of temperature increase for about a day; sometimes the curve shows a plateau or even a downward slope during this period. Temperature then increases rapidly into the thermophilic range, reaching a peak of 140-160° F, generally on the third or fourth day. The compost temperature then declines to within 10° of ambient, generally at the end of 6 to 9 days.

The initial phase of composting is acidic, the pH falling from an initial value of 5.5-6.5 to 4.5-5.0 in the first day or two. The second sharp rise in temperature usually coincides with a rapid increase in pH, and peak temperatures are seldom reached until the pH is 7.0 or above. Most of the thermophilic action occurs under alkaline conditions, the pH reaching 8.0 to 8.5 as temperatures reach their peak and start to decline. There is usually a slight drop in pH near the end of a run.

Moisture and carbon dioxide in the outlet gases increase to a peak nearly simultaneously with the peak temperature and then decrease. Generally the CO_2 output slightly exceeds total H_2O output during the first half of a run, and the reverse is true during the last half.

Analyses for the same run as shown in figure 3 are given in table 1.

Table I: Physical and Chemical Analyses of Compost in a Typical Composting Run (Run 25, Drum 4).

Day	Moisture % (WW)	Volatile solids % (DW)	Carbon % (DW)	Nitrogen % (DW)	C/N
0	65.7	93.1	41.7	1.22	34
3	66.8	91.4	-	-	-
6	70.1	91.2	42.9	1.54	28

Percentage values of moisture, nitrogen and protein increased. Carbon for all 6 drums in this run averaged 40.3 per cent on the last day, indicating little or no change during the run, although results for drum 4 show a slight increase. The C/N and volatile solids showed a decrease during the run.

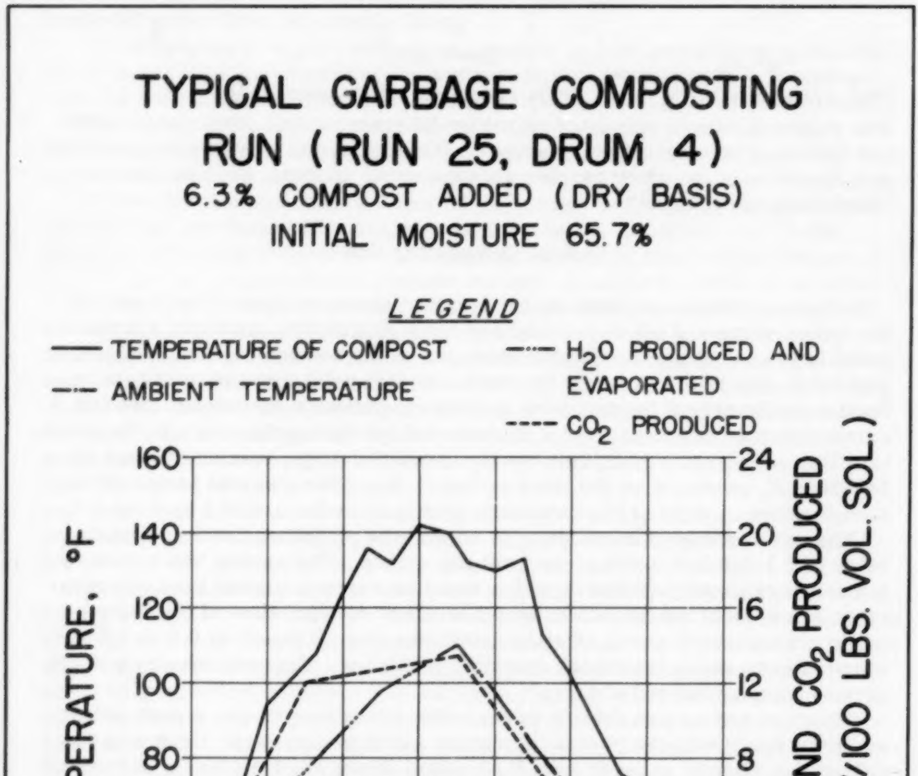

TYPICAL GARBAGE COMPOSTING
RUN (RUN 25, DRUM 4)
6.3% COMPOST ADDED (DRY BASIS)
INITIAL MOISTURE 65.7%
LEGEND
TEMPERATURE OF COMPOST
AMBIENT TEMPERATURE
H2O PRODUCED AND EVAPORATED
CO2 PRODUCED
TEMPERATURE, °F
160
140
120
100
80
60
40
H2O AND CO2 PRODUCED (LBS/DAY/100 LBS. VOL. SOL.)
24
20
16
12
8
4
0
pH
9
8
7
6
5
4
0
1
2
3
4
5
6
7
DAYS
DHEW-PHS-CDC
SAVANNAH, GA.-APR., 1955

Figure 3.

While percentage values appear to show little change during composting, the absolute weights show a marked decrease as indicated in table 2, and figure 4.

Table 2: Weight Balance - Typical Composting Run (Run 25, Drum 4).

	Weight in Pounds									
	Composting Materials					O_2 Used	H_2O discharged		CO_2 produced	Total
	Dry Weight			Moisture	Total		Evaporated	Produced		
	Vol. Sol.	Ash	Total							
Intake	13.6	1.0	14.6	29.2	43.8	6.0	-	-	-	49.8
Output	9.8	1.0	10.8	25.2	36.0	-	4.0	2.6	7.2	49.8
Loss	3.8	-	3.8	4.0	7.8					
% Loss	27.9	-	26.0	13.7	17.8					

Losses in dry weight, especially the volatile solids component, and total weight are considered important. Moisture loss by evaporation may be increased greatly by using more air, by faster stirring, or by better insulation of the units. Amounts of oxygen used and of CO_2 and H_2O produced are direct measurements of the activity of the micro-organisms. Oxygen was computed by subtracting the initial charge, 43.8 lb, from the total output, 49.8 lb. This value, 6.0 lb, can also be checked by means of discharged materials and volatile solids lost as follows:

H_2O produced = 2.6 lb;	H_2 = 0.29 lb;	O_2 = 2.31 lb
CO_2 produced = 7.2 lb;	C = 1.96 lb;	O_2 = 5.24 lb
Total discharged:	H_2 and C = 2.25 lb;	O_2 = 7.55 lb

Total C, H_2 and O_2 recovered in outlet gases = 9.8 lb
Volatile solids lost = 3.8 lb

Difference, made up by O_2 from air = 6.0 lb

Actually, 6.6 lb of moisture was recovered in Drierite tubes during the run. The loss in moisture from the compost, 4.0 lb, was subtracted from the total moisture to give the net amount of H_2O produced by oxidation, 2.6 lb. Part of the O_2 needed for the oxidation, 1.55 lb, comes from the organic constituents, primarily carbohydrates (CHO), while the majority, 6.0 lb, was drawn from the air supplied. The respiratory quotient for this run is:

$$\frac{\text{Vol. } CO_2}{\text{Vol. } O_2} = \frac{7.2/44}{6.0/32} = \frac{0.164}{0.188} = 0.87$$

Average results for 25 runs with 1 to 6 drums in operation are summarized in tables 3 and 4, giving analyses and weight losses.

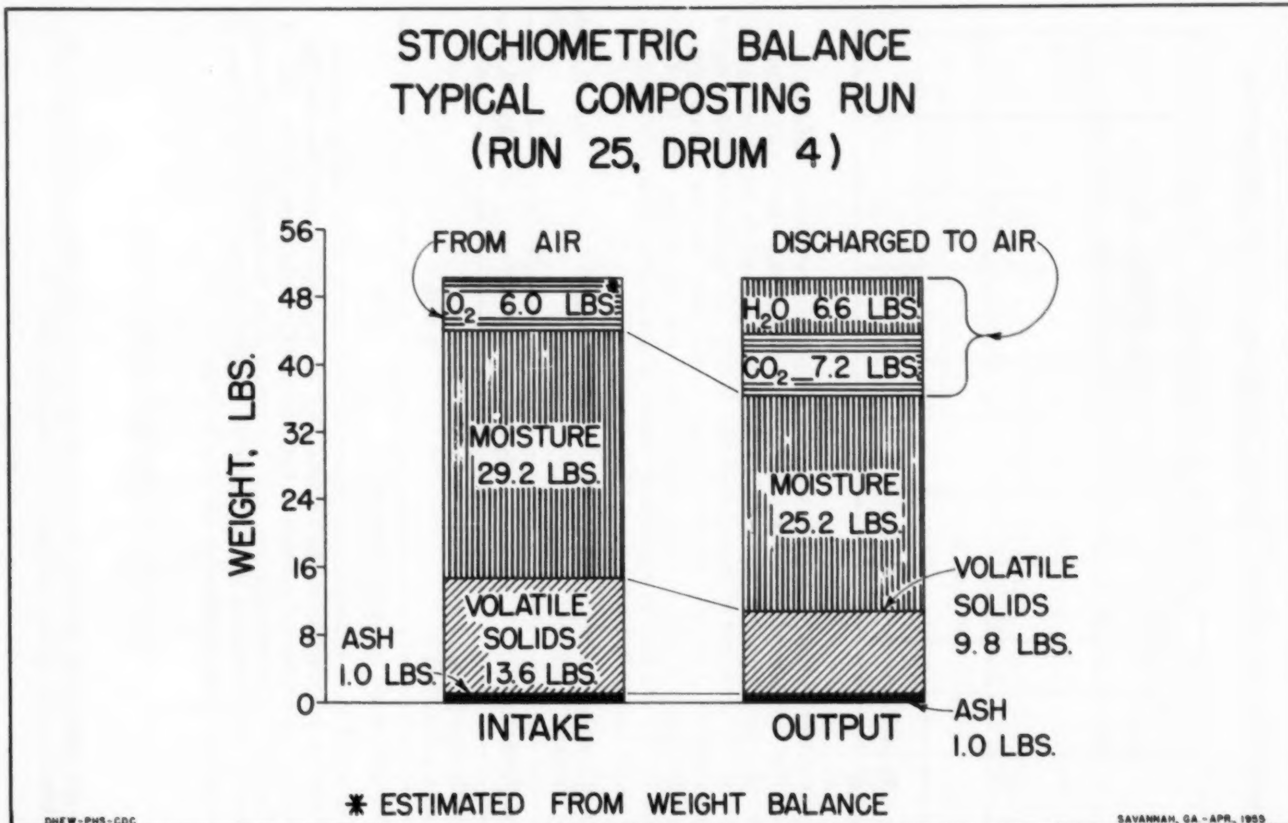

STOICHIOMETRIC BALANCE
TYPICAL COMPOSTING RUN
(RUN 25, DRUM 4)
WEIGHT, LBS.
56
48
40
32
24
16
8
0
FROM AIR
O_2 6.0 LBS.
*
MOISTURE 29.2 LBS.
VOLATILE SOLIDS 13.6 LBS.
ASH 1.0 LBS.
INTAKE
DISCHARGED TO AIR
H_2O 6.6 LBS.
CO_2 7.2 LBS.
MOISTURE 25.2 LBS.
VOLATILE SOLIDS 9.8 LBS.
ASH 1.0 LBS.
OUTPUT
* ESTIMATED FROM WEIGHT BALANCE
DHEW-PHS-CDC
SAVANNAH, GA - APR., 1959

Figure 4.

Table 3: Physical and Chemical Analyses of Compost. Averages of 1 to 6 drums and 25 runs.

	Moisture % (WW)	Volatile solids % (DW)	Carbon %(DW)	Nitrogen % (DW)	C/N	pH
Initial	56.4	89.4	42.1	1.21	35	5.74
Final	53.3	85.3	41.9	1.67	25	7.99

Table 4: Weights and Losses in Composting Materials (pounds). Averages of 1 to 6 drums and 25 runs.

	Dry Weight			Moisture	Total
	Vol. Sol.	Ash	Total		
Intake	11.3	1.4	12.7	17.1	29.8
Output	7.9	1.3	9.2	11.4	20.6
Loss	3.4	0.1	3.5	5.7	9.2
% Loss	30.1	7.1	27.6	33.3	30.9

Weight balances have been computed for 9 runs with from 1 to 6 drums as shown in table 5.

Table 5: Weight Balance. Averages of 1 to 6 drums and 9 runs.

	Weight in Pounds									
	Composting Materials					O_2 Used	H_2O discharged		CO_2 produced	Total
	Dry Weight			Moisture	Total		Evaporated	Produced		
	Vol. Sol.	Ash	Total							
Intake	14.3	1.5	15.8	22.3	38.1	6.1	-	-	-	44.2
Output	10.5	1.4	11.9	14.6	26.5	-	7.7	2.4	7.6	44.2
Loss	3.8	0.1	3.9	7.7	11.6					
% Loss	26.6	6.7	24.7	34.5	30.5					

Average R.Q. for 9 Runs = 0.91

In general, losses in volatile solids have varied between 17 and 53 per cent with an average of 30 per cent in 25 runs. This indicates that nearly one-third of the organic matter is decomposed to water and carbon dioxide. The moisture and carbon dioxide given off weigh slightly more than 2.6 times the

weight of volatile solids lost, this extra weight coming from oxygen used in the decomposition. The slight loss in ash content shown in tables 4 and 5 is probably the result of sampling or other errors. However, the fact that there was no appreciable gain in ash content indicates that little mineralization, if any, was occurring.

The composting periods averaged about 7.3 days; however, in some cases runs were continued for 1 to 3 days longer than the time for compost temperatures to reach within 10^{o} of ambient. Although compost temperatures in most cases drop to within 10^{o} of room temperature, the material at the end of a run still contains a considerable amount of organic matter subject to decomposition. The more readily oxidizable matter is decomposed,and the structure and character of the material is changed considerably. Paper, wood, cellophane, rags, bones and similar materials show little evidence of decomposition. However, most of the wet garbage is no longer recognizable. Citrus peels and banana stalks can be distinguished,but they are shriveled to less than half their original size and are quite dark in color. The finished compost has an earthy or moldy odor like that of well-digested sewage sludge. It is dark brown when wet, light brown when dry, and is very fluffy after being air dried and finely ground. It is presumed that such materials as sugars, starches, pentosans, etc. are completely destroyed,whereas there is little or no destruction of cellulosic matter which probably makes up the bulk of the residual organic material. The average C/N was reduced from about 35 to 25 during composting. Soil humus has a C/N of about 10 regardless of the original source of the organic matter, i.e. peat moss, manures, compost.[15] It seems unlikely that garbage or municipal wastes can be produced with a C/N of this order by composting. However, garbage composts having C/N ratios up to 25 or 30 could be expected to be readily converted to soil humus under most situations. A suitable test for the desirable end point of composting has not been developed thus far. Such a test should take into consideration both agricultural and health implications of the material which may be distributed for use by the public.

Data available from 17 runs in which initial and final nitrogen contents were determined show that there was no loss of nitrogen for the average values:

Nitrogen Balance. Averages for 17 runs.

	Initial	Final
Nitrogen, % (DW)	1.21	1.67
Dry weight, lb	11.8	8.55
Nitrogen, lb	0.143	0.143

Some nitrogen loss was evident in a few runs by the detection of an ammonia odor in outlet gases. The presence of ammonia was variable,and the factors effecting its production have not been studied.

Physical Factors for Optimum Composting

Mention has been made of insulation and heating to speed up the composting process. Neither appears necessary for large units, including those of commercial size, but one or the other appears necessary for very small laboratory units where the area of surface exposure is large in proportion to the mass of material.

Duplicate runs were made with each of the six drums operating at a different stirring rate throughout the run and with all other variables held as constant as feasible. Conditions for the two runs are shown in table 6.

Table 6: Conditions for Study of Stirring Rate Variation.

	Run 23		Run 26	
Initial charge (same for each drum):				
Garbage and Refuse, lb	28.0		34.0	
Compost, lb	2.0		2.0	
Total, lb	30.0		36.0	
Initial moisture, % (WW)	55.4		51.6	
Initial volatile solids, % (DW)	91.5		90.7	
Air supplied, cfm	0.26		0.25	
Stirring rates:-	Drum	rpm	Drum	rpm
Low speed	6 5	0.035 0.12	1 2	0.05 0.10
Medium speed	1 4	0.20 0.27	3 4	0.19 0.35
High speed	3 2	0.52 0.53	6 5	0.55 0.61

To determine the effect of stirring speed on temperature of compost (figure 5), values were averaged for the two drums with lowest speeds, the two with middle speeds, and the two with highest speeds—four values in each group. Results indicate little difference within the speed ranges tested. This, of course, applies to the type of stirring in these particular units in which only two curved stirring arms were attached to the shaft of each drum. This method of stirring is rather inefficient in that the 1/2-inch stirring arms sometimes cut paths through the compost rather than mixing or moving the entire contents of the drums,and a certain amount of caking of the material occurs on the bottom, on stirring arms, and on the temperature sensing element at times. Any slight advantage appears to be in favor of the stirring rates in the range of 0.19 to 0.35 rpm because of slightly higher peak temperature and quicker return to room temperature of the compost. Extremely slow speeds (0.035 and 0.05 rpm) resulted in the lowest peak temperature, the slowest return to room temperature, and the smallest losses in weight of volatile solids and moisture. In general, therefore, it is concluded that stirring rates of 0.10 to 0.61 rpm, and possibly faster rates, should be satisfactory for composting in the experimental units. If more efficient stirring is achieved, or if the entire contents of a composter are tumbled or constantly mixed, different stirring or tumbling rates might be indicated. In addition, high moisture in the initial mix may require faster turning than low moisture. Better stirring may also reduce aeration requirements by providing more intimate contact between the organic particles and oxygen to be utilized and by better sweeping out of waste gases and vapors.

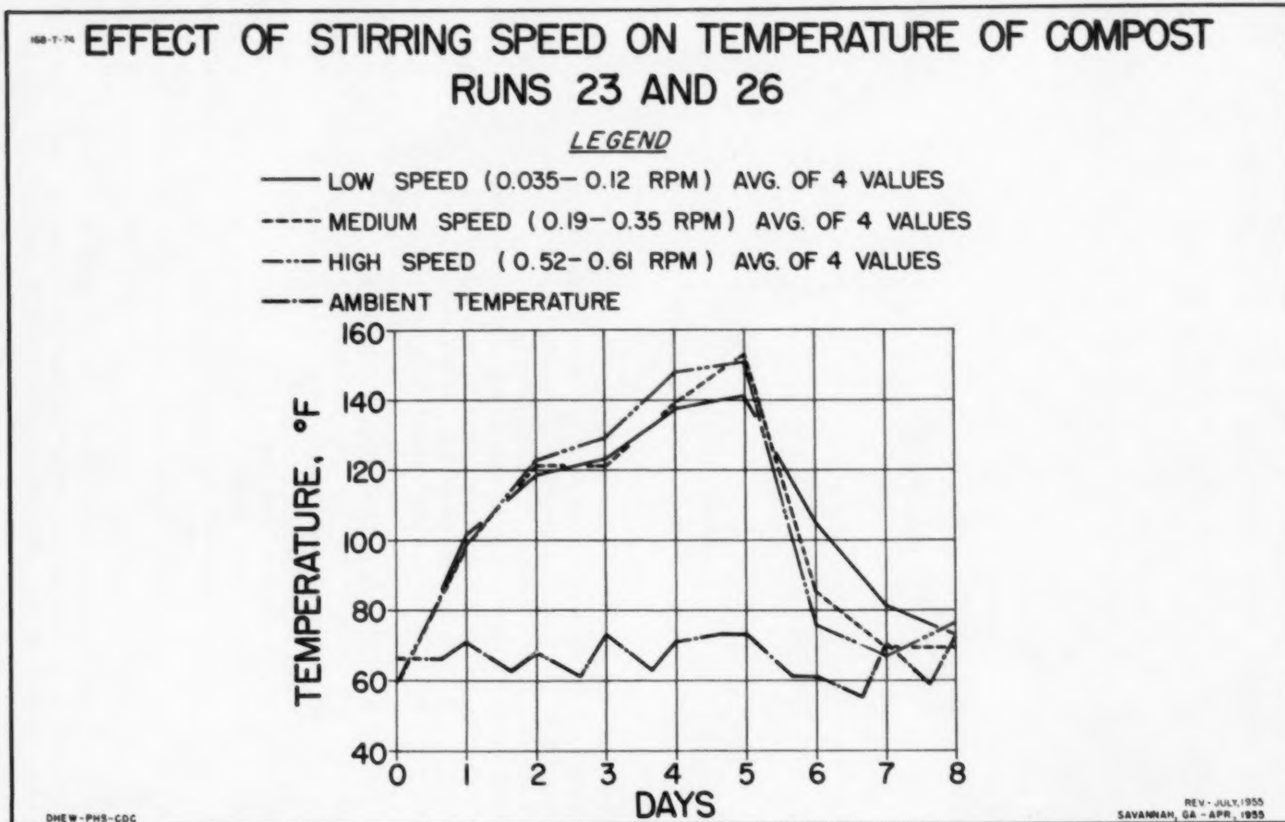

168-T-74
EFFECT OF STIRRING SPEED ON TEMPERATURE OF COMPOST
RUNS 23 AND 26
LEGEND
LOW SPEED (0.035– 0.12 RPM) AVG. OF 4 VALUES
MEDIUM SPEED (0.19– 0.35 RPM) AVG. OF 4 VALUES
HIGH SPEED (0.52– 0.61 RPM) AVG. OF 4 VALUES
AMBIENT TEMPERATURE
TEMPERATURE, °F
160
140
120
100
80
60
40
0
1
2
3
4
5
6
7
8
DAYS
DHEW-PHS-CDC
REV - JULY, 1955
SAVANNAH, GA - APR., 1959

Figure 5.

Variation in aeration rate had a pronounced effect on the course of composting. In runs 24 and 27 aeration was varied with all other factors held as constant as possible (table 7).

Table 7: Conditions for Study of Variation in Aeration.

	Run 24		Run 27	
Initial charge (same for each drum):				
Garbage and Refuse, lb	30.0		34.0	
Compost, lb	2.5		2.0	
Total, lb	32.5		36.0	
Initial moisture, % (WW)	58.3		51.7	
Initial volatile solids,% (WW)	91.8		90.7	
Stirring rate, rpm	0.08-0.10		0.10-0.11	
Air supplied:-	Drum	cfm	Drum	cfm
Low aeration	1 2	0.035 0.055	6 5	0.036 0.055
Medium aeration	3 4	0.11 0.25	4 3	0.10 0.26
High aeration	5 6	0.35 0.67	2 1	0.36 0.65

Combining temperature values for both runs in the two low, medium, and high aeration rates results in the curves shown in figure 6. Low aeration, 0.035-0.055 cfm per drum or 4-6.4 cu ft per day per lb volatile solids in the initial charge, resulted in a late peak temperature (seventh day) and incomplete compost by the ninth day. Medium aeration, 0.10-0.26 cfm per drum or 9-29 cu ft per day per lb volatile solids, resulted in a peak temperature occurring on the fourth day with a slow decline until the ninth day when the composting was considered to be completed. Following the composting run, materials in these drums did not re-heat. With high aeration values, 0.35-0.67 cfm per drum or 33-78 cu ft per day per lb volatile solids, the peak temperature was also reached on the fourth day of composting,but this was followed by a rapid decline to room temperature by the sixth day. However, even after continuing composting for three additional days, the compost re-heated to a temperature of over 140^{o} F after being removed from the drum, mixed, aerated and placed in open cans. This was a higher value than attained during the primary composting run. It may be concluded that low aeration provides either insufficient oxygen or insufficient sweeping out of waste gases, resulting in a prolonged period of composting but with no re-heating of the material after initial composting. Medium or adequate aeration values, in the range of 10-30 cu ft per day per lb volatile solids, result in a relatively rapid climb to the peak temperature, a slow decline to room temperature, followed by inability of the compost to re-heat. High aeration results in rapid cooling and dehydration of the compost, with seeming completion of the process in a very short period, but with re-heating upon subsequent mixing and storage. The latter indicates that oxidation was incomplete and the compost was not a finished product, but one which could become a nuisance or a health hazard

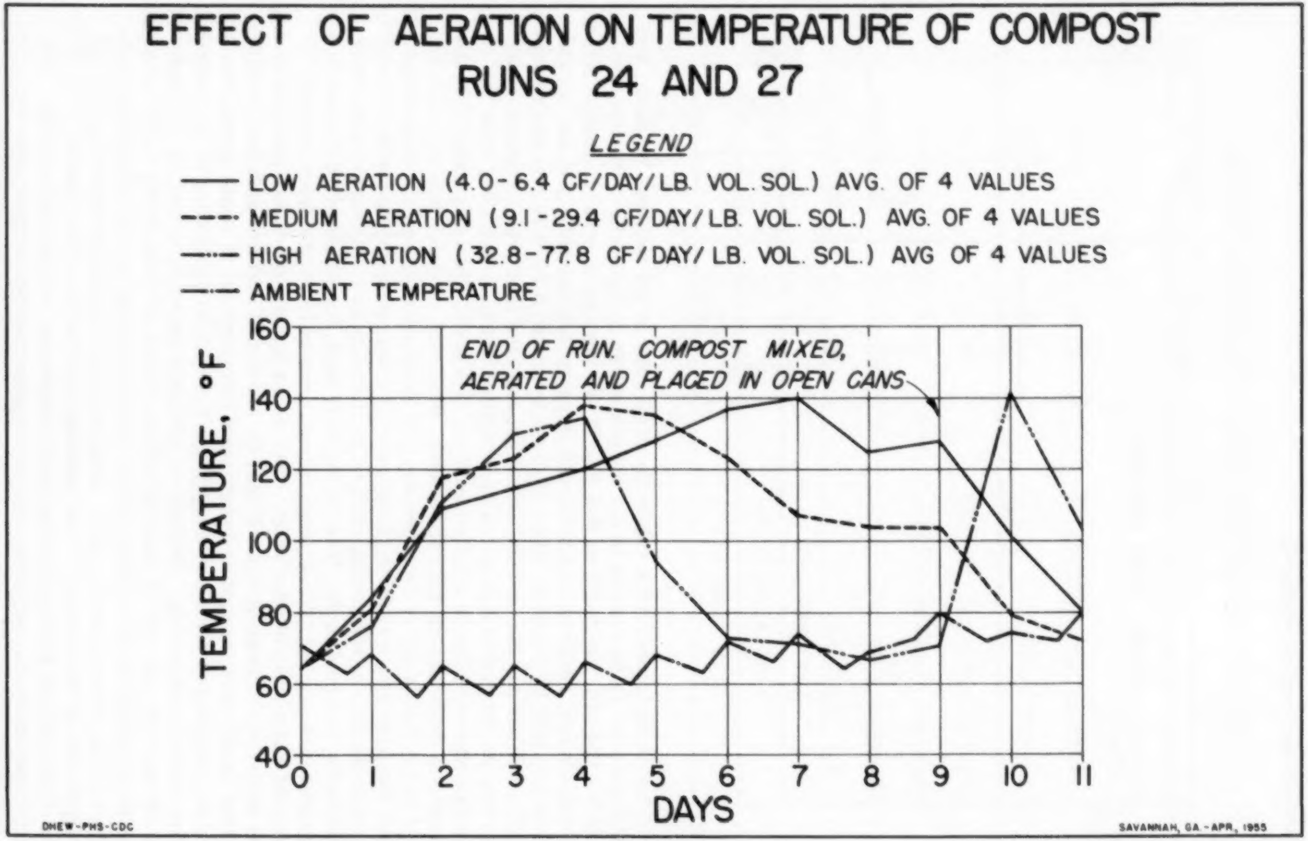

EFFECT OF AERATION ON TEMPERATURE OF COMPOST
RUNS 24 AND 27
LEGEND
LOW AERATION (4.0-6.4 CF/DAY/LB. VOL. SOL.) AVG. OF 4 VALUES
MEDIUM AERATION (9.1-29.4 CF/DAY/LB. VOL. SOL.) AVG. OF 4 VALUES
HIGH AERATION (32.8-77.8 CF/DAY/LB. VOL. SOL.) AVG OF 4 VALUES
AMBIENT TEMPERATURE
END OF RUN. COMPOST MIXED, AERATED AND PLACED IN OPEN CANS
TEMPERATURE, °F
160
140
120
100
80
60
40
0 1 2 3 4 5 6 7 8 9 10 11
DAYS
DHEW-PHS-CDC
SAVANNAH, GA.-APR., 1955

Figure 6.

Table 8: Conditions for Study of Variation in Moisture.

	Run 25			Run 29		
Initial charge (same for all drums):						
Garbage and Refuse, lb	25.0			22.9		
Compost, lb	1.25			1.25		
Total, excluding added moisture, lb	26.25			24.15		
Initial volatile solids, % (DW)	93.1			93.1		
Air supplied, cfm	0.25			0.25		
Stirring rate, rpm	0.09-0.10			0.14-0.16		
	Drum	Moisture added, lb	Initial moisture % (WW)	Drum	Moisture added, lb	Initial moisture % (WW)
Low moisture	1 2	- 4.0	44.6 52.9	1 2	- 3.15	40.2 47.1
Medium Moisture	3 4	9.5 17.5	58.7 65.7	3 4 5	7.65 13.75 22.45	54.7 61.9 69.0
High moisture	5 6	26.3 36.8	72.0 76.6	6	36.05	76.0

unless further treated to reduce the oxidizable organic matter.

Moisture also had a noticeable effect on the course of composting. In runs 25 and 29 moisture content of the initial mix was varied and all other factors maintained constant (table 8).

In computing values for the temperature curves (figure 7), values from drums 1 and 2 of both runs were averaged indicating low moisture (40-53 per cent), values from drums 3 and 4, Run 25, and drums 3, 4 and 5, Run 29, were averaged indicating medium moisture (55-69 per cent), and the remaining values indicating high moisture (72-77 per cent) were averaged. The curves for all ranges of moisture showed a peak temperature on the third day. That for the low moisture came to a peak of 130° F, dropped to ambient temperature by the sixth day, and then re-heated to 101° F after adjusting moisture, mixing and aerating. Final moisture values were considerably lower than the initial values and the loss of dry weight and volatile solids weight was small. With medium moisture, the peak temperature was 147° F and the compost was at room temperature on the sixth day with no subsequent re-heating. Dry and volatile solids weight losses were favorable (17-31 per cent) and the per cent final moisture content was the same or slightly higher than initially. The curve for the high moisture drums has a peak temperature of only 109° F and by the sixth day the temperature was still 20° above ambient (89°). After partially drying the compost, mixing and aerating, the temperature rose to about 97° F indicating that the composting had not been completed. Under the conditions of these experiments it is concluded that optimum composting occurs when the moisture content of the refuse is started and maintained in a range of 55 to 69 per cent. Values below about 50 per cent moisture are too low, and values above about 72 per cent moisture are too high. These values apply to garbage and refuse with a relatively high paper content, as it was necessary to retain much of the paper found in the raw refuse in order to keep the initial moisture low in the basic materials for these experiments.

Correlation of CO_2 and H_2O in Outlet Gases with Temperature of Compost

As production rates of CO_2 and H_2O during composting represent the rate at which decomposition is proceeding, they were compared with compost temperatures to determine correlation. Initial scatter diagrams on arithmetic paper showed good correlation but the points seemed to lie on a concave curve. Plotting points on semi-log paper, with CO_2 and H_2O production and evaporation rates on the log scale gave better correlation and more nearly straight lines. This is understandable because the micro-organisms undergo a logarithmic phase of growth under favorable conditions. Figures 8 and 9 show examples of correlations obtained, together with the lines of best fit computed by the method of least squares.[16]

Correlation between CO_2 production rate and temperature of compost is shown for Run 27 in which the six drums had widely different aeration rates. A correlation coefficient (r) of 0.844 was obtained with 54 pairs of observations (N), indicating excellent correlation. The line of best fit is $\text{Log } Y = 0.01177X - 0.7093$, in which Y is the rate of CO_2 production in lb per day per 100 lb volatile solids, and X is the temperature of compost in °F.

A similar correlation coefficient and line of best fit has been computed for a total of 8 runs involving 245 pairs of observations, presented in table 9.

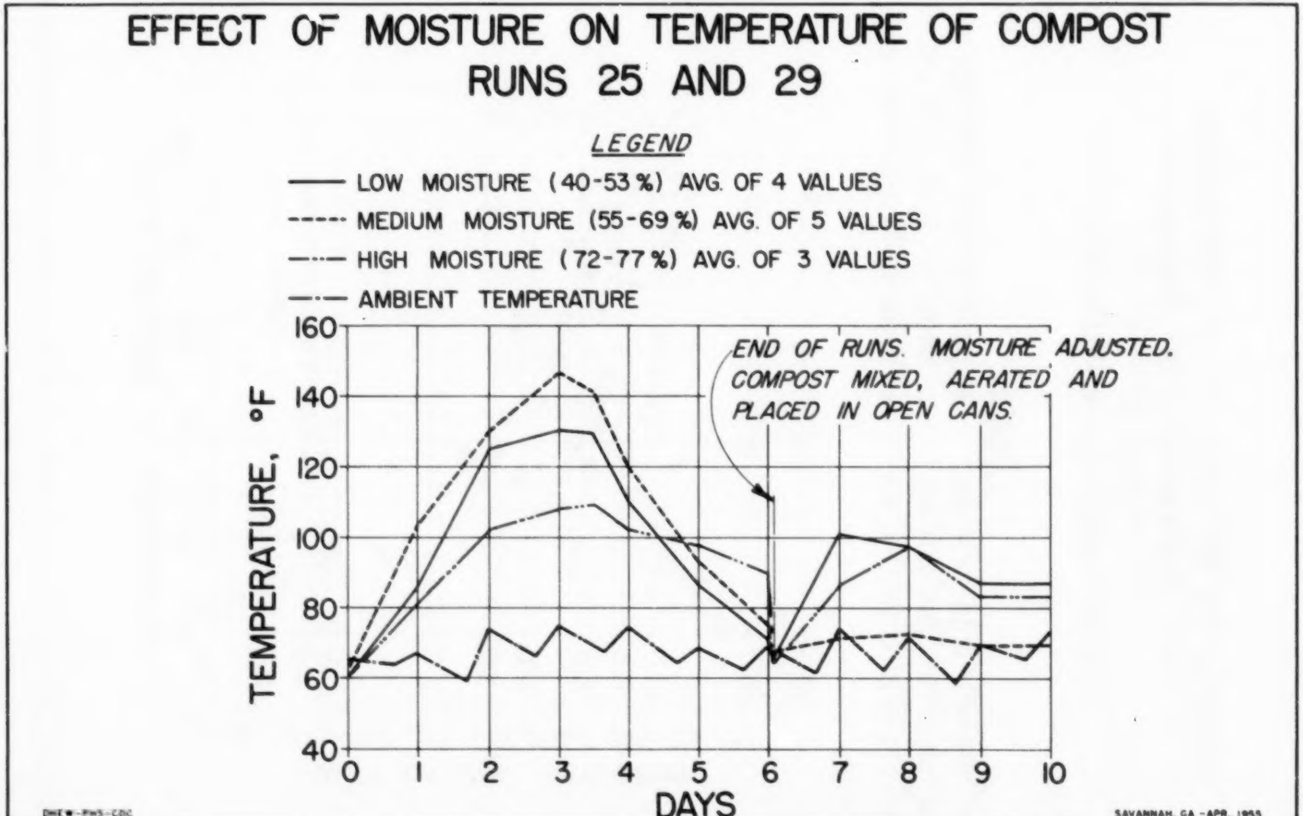

EFFECT OF MOISTURE ON TEMPERATURE OF COMPOST
RUNS 25 AND 29
LEGEND
LOW MOISTURE (40-53 %) AVG. OF 4 VALUES
MEDIUM MOISTURE (55-69 %) AVG. OF 5 VALUES
HIGH MOISTURE (72-77 %) AVG. OF 3 VALUES
AMBIENT TEMPERATURE
END OF RUNS. MOISTURE ADJUSTED. COMPOST MIXED, AERATED AND PLACED IN OPEN CANS.
TEMPERATURE, °F
160
140
120
100
80
60
40
0
1
2
3
4
5
6
7
8
9
10
DAYS
DHEW-PHS-CDC
SAVANNAH, GA - APR., 1955

Figure 7.

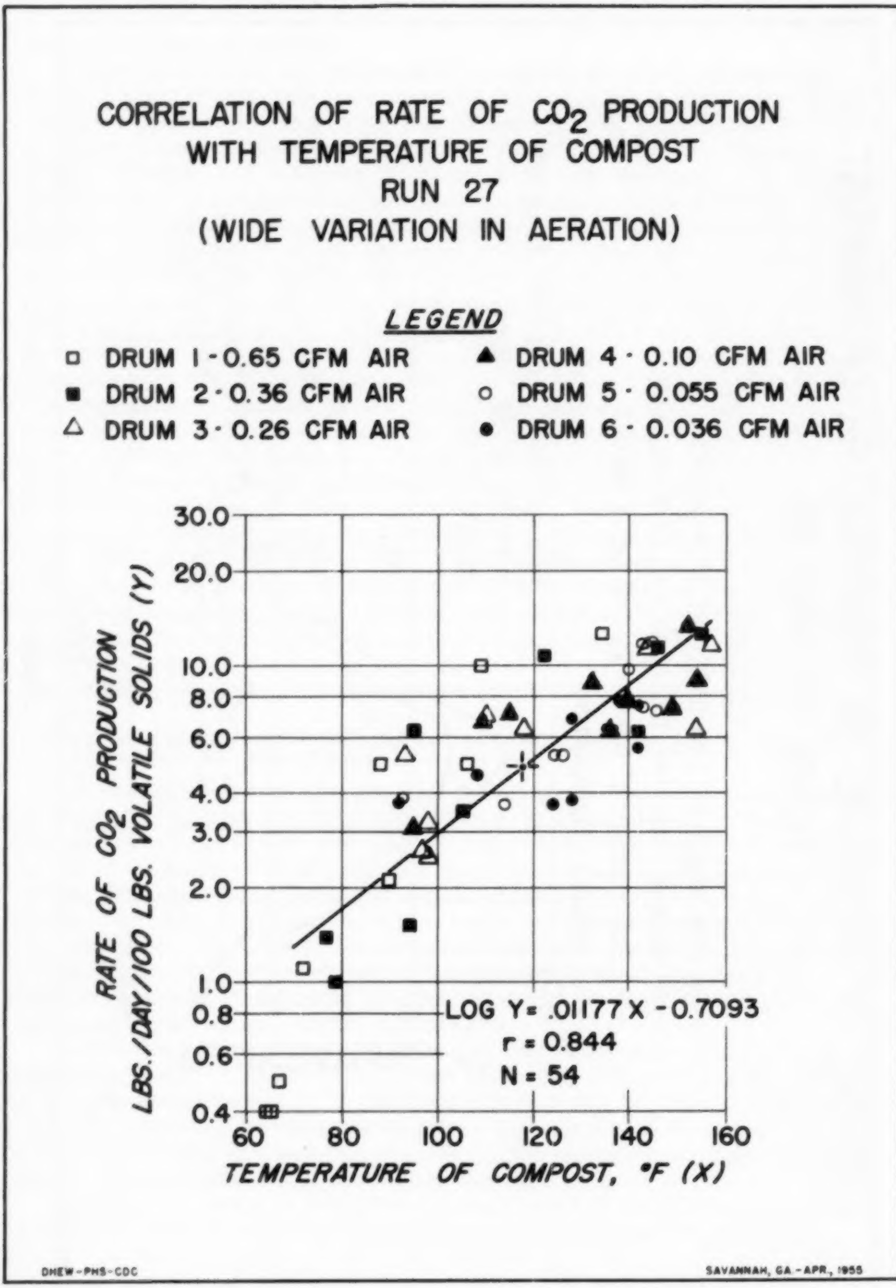

CORRELATION OF RATE OF CO_2 PRODUCTION
WITH TEMPERATURE OF COMPOST
RUN 27
(WIDE VARIATION IN AERATION)
LEGEND
DRUM 1 - 0.65 CFM AIR
DRUM 2 - 0.36 CFM AIR
DRUM 3 - 0.26 CFM AIR
DRUM 4 - 0.10 CFM AIR
DRUM 5 - 0.055 CFM AIR
DRUM 6 - 0.036 CFM AIR
RATE OF CO_2 PRODUCTION
LBS./DAY/100 LBS. VOLATILE SOLIDS (Y)
30.0
20.0
10.0
8.0
6.0
4.0
3.0
2.0
1.0
0.8
0.6
0.4
60
80
100
120
140
160
TEMPERATURE OF COMPOST, °F (X)
LOG Y = .01177 X - 0.7093
r = 0.844
N = 54
DHEW - PHS - CDC
SAVANNAH, GA. - APR., 1955

Figure 8.

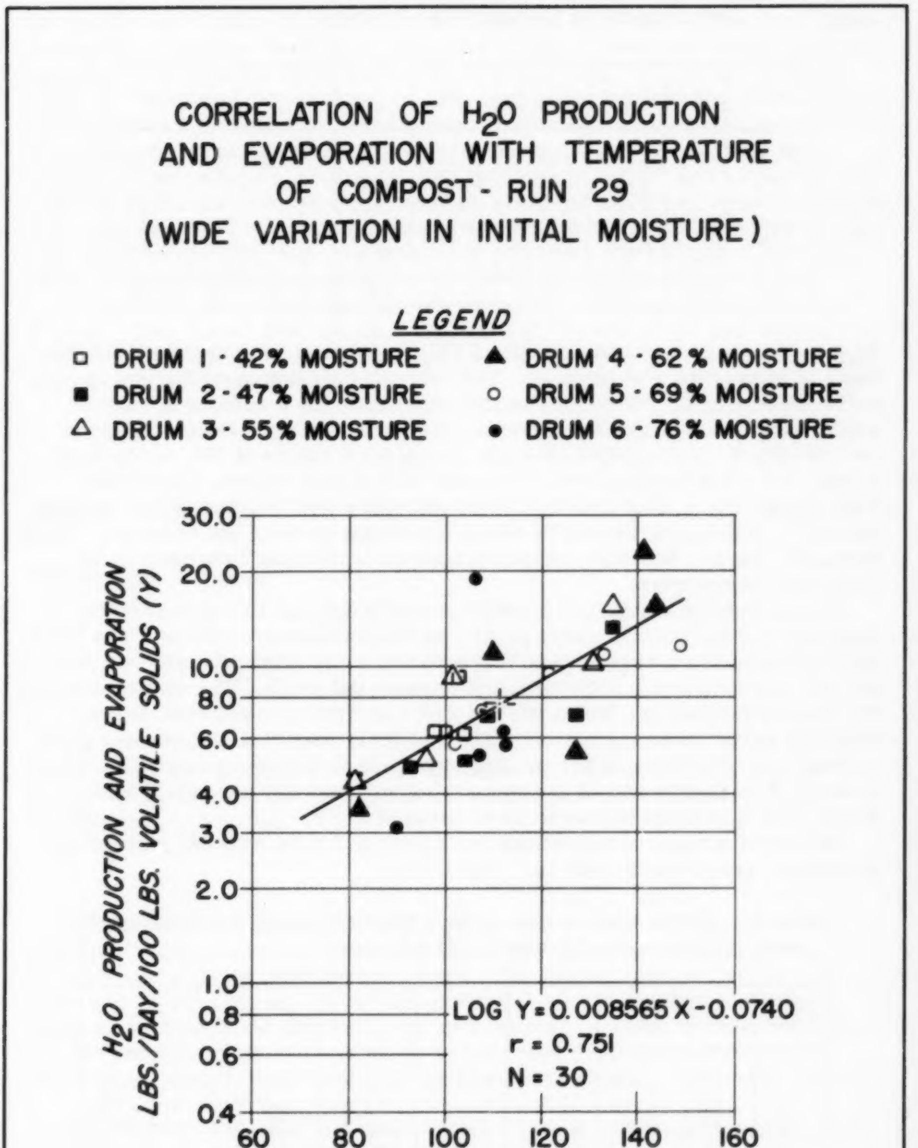

CORRELATION OF H_2O PRODUCTION
AND EVAPORATION WITH TEMPERATURE
OF COMPOST - RUN 29
(WIDE VARIATION IN INITIAL MOISTURE)
LEGEND
DRUM 1 - 42% MOISTURE
DRUM 2 - 47% MOISTURE
DRUM 3 - 55% MOISTURE
DRUM 4 - 62% MOISTURE
DRUM 5 - 69% MOISTURE
DRUM 6 - 76% MOISTURE
30.0
20.0
10.0
8.0
6.0
4.0
3.0
2.0
1.0
0.8
0.6
0.4
60
80
100
120
140
160
H_2O PRODUCTION AND EVAPORATION
LBS./DAY/100 LBS. VOLATILE SOLIDS (Y)
TEMPERATURE OF COMPOST, °F (X)
LOG Y = 0.008565 X - 0.0740
r = 0.751
N = 30
DHEW-PHS-CDC
SAVANNAH, GA.-APR., 1955

Figure 9.

Table 9: Correlation of Rate of CO_2 Production (Y) with Temperature of Compost(X) - 8 runs.

Runs	N	Y_{mg}	X_m	r	Line of Best Fit
14-16	47	7.30	124.9	0.653	Log Y = .01225X-.6660
25	36	5.07	100.4	0.871	Log Y = .01091X-.3908
26	54	5.31	111.2	0.832	Log Y = .00896X-.2715
27	54	4.79	118.0	0.844	Log Y = .01177X-.7093
28	24	8.02	127.9	0.784	Log Y = .00989X-.3600
29	30	5.65	111.3	0.712	Log Y = .01181X-.5626
All	245	5.75	115.4	0.791	Log Y = .01012X-.4084

Y_{mg} is the geometric mean of rate of CO_2 production. X_m is the arithmetic mean of temperature of compost. The over-all correlation coefficient is 0.791, indicating that very good correlation exists for a number of runs in which the initial charges and other factors varied widely. From the line of best fit, log Y = 0.01012X-0.4084, one can predict values of CO_2 production rates for a given temperature of compost with a good degree of accuracy. This means that a plant operator could tell fairly well how the course of composting is proceeding merely by taking the temperature of the compost. These particular values, however, might not apply to continuous flow units or to plant-size composters.

Figure 9 shows a similar correlation coefficient and line of best fit for moisture collected in the outlet gases and temperature of compost. The moisture in this case represents both that which is evaporated from the compost and that produced by decomposition of organic materials. The scatter diagram for Run 29 includes six drums each of which started with material having a different initial moisture content. The r of 0.751 with N of 30 indicates good correlation. The formula for the line of best fit is Log Y = 0.008565X-0.0740 in which Y is H_2O produced and evaporated in lb per day per 100 lb volatile solids, and X is again temperature of compost in ^{o}F.

Results of similar computations for a total of 9 runs with 287 pairs of observations are given in table 10.

Table 10: Correlation of Rate of H_2O Production and Evaporation (Y) with Temperature of Compost (X) - 9 runs.

Runs	N	Y_{mg}	X_m	r	Line of Best Fit
14-16	47	12.60	124.9	0.475	Log Y = .007519X + .1614
21	48	5.40	100.5	0.658	Log Y = .008836X - .1590
23	36	8.39	119.4	0.830	Log Y = .01162X - .4687
25	36	5.36	100.4	0.970	Log Y = .008837X - .1582
26	54	6.26	111.2	0.923	Log Y = .007410X - .0274
28	36	9.88	128.9	0.916	Log Y = .009773X - .2646
29	30	7.58	111.3	0.751	Log Y = .008565X - .0740
All	287	7.52	113.6	0.827	Log Y = .009142X - .1619

The over-all coefficient of correlation is 0.827 and formula for line of best fit is $\log Y = 0.009142X - 0.1619$. Two runs, 24 and 27, were omitted from these calculations because these were the aeration experiments and widely different aeration rates greatly affect the moisture evaporated. Figure 10 shows the effect of changing aeration rates on the relationship between the rate of moisture produced and evaporated and the temperature of compost. High air flows evaporate much more moisture from the compost than low air flows even though the temperature of compost may be the same. There is no correlation between H_2O produced and evaporated and temperature under these conditions. The lines for each drum were drawn in by eye. Under conditions where aeration is in the optimal range, it is possible to predict the amount of moisture given off in the outlet gases from the temperature of the compost.

Continuous analyses of H_2O and CO_2 discharge rates have been made for 9 runs. From these data, together with loss in volatile solids and oxygen utilized, it is possible to solve the equation for an empirical formula for the organic matter destroyed:

$$\underset{\text{(volatile solids lost)}}{\overset{3.8\text{ lb}}{C_xH_yO_z}} + \underset{(O_2\text{ used})}{\overset{6.1\text{ lb}}{bO_2}} \longrightarrow \overset{7.6\text{ lb}}{xCO_2\uparrow} + \overset{2.4\text{ lb}}{y/2H_2O\uparrow} \quad (CO_2 \text{ and } H_2O \text{ produced})$$

The equation becomes:

$$\underset{(576)}{2C_{13}H_{20}O_7} + \underset{(928)}{29\ O_2} \longrightarrow \underset{(1144)}{26\ CO_2\uparrow} + \underset{(360)}{20\ H_2O\uparrow}$$

The respiratory quotient (R.Q.) for the above reaction is 0.90. It is expected that these values will change with the raw materials and with the stage and duration of composting.

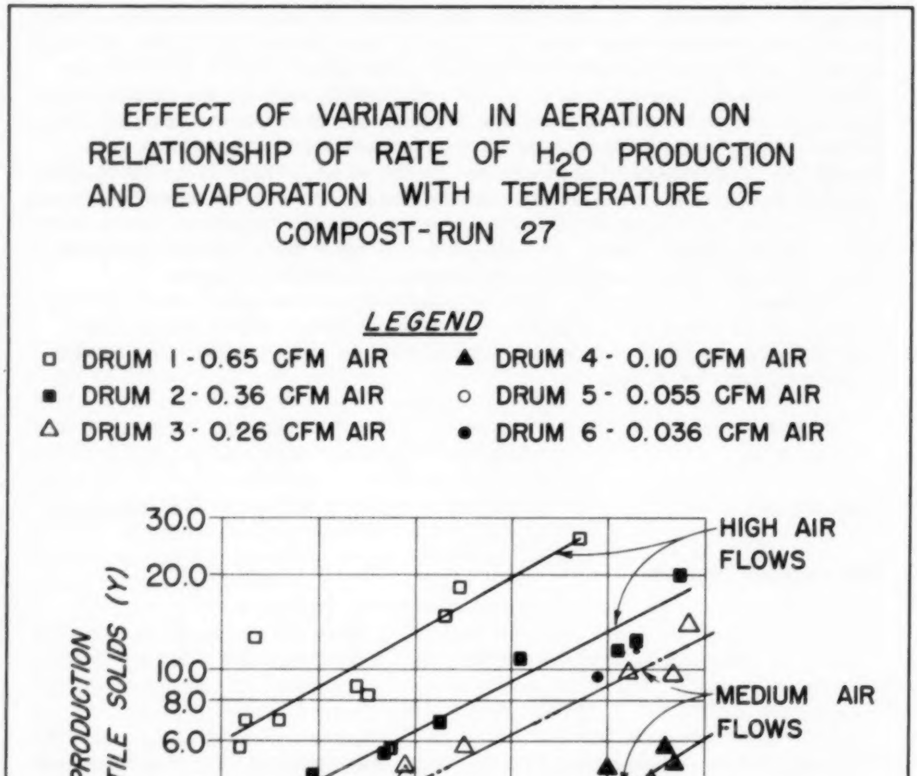
SUMMARY

Composting of combined refuse from the City of Savannah has been successfully accomplished in laboratory batch-type mechanical units in which aeration and stirring have been provided. The period required has varied from 4 to 10 days during which time aerobic thermophilic decomposition takes place, producing temperatures up to 160° F. Carbon dioxide and water are the two major products given off in the outlet gases and both correlate well logarithmically with the temperature of the compost. Respiratory quotients of 0.87 to 0.91 $\frac{(\text{vol. } CO_2)}{(\text{vol. } O_2)}$ have been obtained for the oxidation reaction.

Duplicate runs made with six units indicate:

a) the rate of stirring the compost is not a critical factor and stirring rates of 0.1 to 0.6 rpm or higher may be satisfactory with the type of unit used.

b) optimum aeration rates under the conditions tested were from 10 to 30 cu ft of air per day per lb of volatile solids. Lower rates resulted in prolonged composting and higher rates resulted in rapid cooling and drying of the composting garbage.



EFFECT OF VARIATION IN AERATION ON RELATIONSHIP OF RATE OF H_2O PRODUCTION AND EVAPORATION WITH TEMPERATURE OF COMPOST-RUN 27
LEGEND
DRUM 1 - 0.65 CFM AIR
DRUM 2 - 0.36 CFM AIR
DRUM 3 - 0.26 CFM AIR
DRUM 4 - 0.10 CFM AIR
DRUM 5 - 0.055 CFM AIR
DRUM 6 - 0.036 CFM AIR
RATE OF H_2O PRODUCTION LBS./DAY/100 LBS. VOLATILE SOLIDS (Y)
TEMPERATURE OF COMPOST, °F (X)
HIGH AIR FLOWS
MEDIUM AIR FLOWS
LOW AIR FLOWS
30.0
20.0
10.0
8.0
6.0
4.0
3.0
2.0
1.0
0.8
0.6
0.4
60
80
100
120
140
160
DHEW - PHS - CDC
SAVANNAH, GA. - APR., 1955

Figure 10.

c) optimum moisture content of the refuse was 55 to 69 per cent. Moistures below 50 per cent and above 72 per cent did not permit optimum composting under the test conditions.

The compost produced is not completely decomposed,and additional experiments are needed to determine if it is suitable for use as a soil conditioner and humus as determined by both public health and agricultural criteria.

ACKNOWLEDGMENT

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DECEMBER: 558(ST), 559(ST), 560(ST), 561(ST), 562(ST), 563(ST)^c, 564(HY), 565(HY), 566(HY), 567(HY), 568(HY)^c, 569(SM), 570(SM), 571(SM), 572(SM)^c, 573(SM)^c, 574(SU), 575(SU), 576(SU), 577(SU), 578(HY), 579(ST), 580(SU), 581(SU), 582(BD).

VOLUME 81 (1955)

JANUARY: 583(ST), 584(ST), 585(ST), 586(ST), 587(ST), 588(ST), 589(ST)^c, 590(SA), 591(SA), 592(SA), 593(SA), 594(SA), 595(SA)^c, 596(HW), 597(HW), 598(HW)^c, 599(CP), 600(CP), 601(CP), 602(CP), 603(CP), 604(EM), 605(EM), 606(EM)^c, 607(EM).

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APRIL: 659(ST), 660(ST), 661(ST)^c, 662(ST), 663(ST), 664(ST)^c, 665(HY)^c, 666(HY), 667(HY), 668(HY), 669(HY), 670(EM), 671(EM), 672(EM), 673(EM), 674(EM), 675(EM), 676(EM), 677(EM), 678(HY).

MAY: 679(ST), 680(ST), 681(ST), 682(ST)^c, 683(ST), 684(ST), 685(SA), 686(SA), 687(SA), 688(SA), 689(SA)^c, 690(EM), 691(EM), 692(EM), 693(EM), 694(EM), 695(EM), 696(PO), 697(PO), 698(SA), 699(PO)^c, 700(PO), 701(ST)^c.

JUNE: 702(HW), 703(HW), 704(HW)^c, 705(IR), 706(IR), 707(IR), 708(IR), 709(HY)^c, 710(CP), 711(CP), 712(CP), 713(CP)^c, 714(HY), 715(HY), 716(HY), 717(HY), 718(SM)^c, 719(HY)^c, 720(AT), 721(AT), 722(SU), 723(WW), 724(WW), 725(WW), 726(WW)^c, 727(WW), 728(IR), 729(IR), 730(SU)^c, 731(SU).

JULY: 732(ST), 733(ST), 734(ST), 735(ST), 736(ST), 737(PO), 738(PO), 739(PO), 740(PO), 741(PO), 742(PO), 743(HY), 744(HY), 745(HY), 746(HY), 747(HY), 748(HY)^c, 749(SA), 750(SA), 751(SA), 752(SA)^c, 753(SM), 754(SM), 755(SM), 756(SM), 757(SM), 758(CO)^c, 759(SM)^c, 760(WW)^c.

AUGUST: 761(BD), 762(ST), 763(ST), 764(ST), 765(ST)^c, 766(CP), 767(CP), 768(CP), 769(CP), 770(CP), 771(EM), 772(EM), 773(SA), 774(EM), 775(EM), 776(EM)^c, 777(AT), 778(AT), 779(SA), 780(SA), 781(SA), 782(SA)^c, 783(HW), 784(HW), 785(CP), 786(ST).

SEPTEMBER: 787(PO), 788(IR), 789(HY), 790(HY), 791(HY), 792(HY), 793(HY), 794(HY)^c, 795(EM), 796(EM), 797(EM), 798(EM), 799(EM)^c, 800(WW), 801(WW), 802(WW), 803(WW), 804(WW), 805(WW), 806(HY), 807(PO)^c, 808(IR)^c.

OCTOBER: 809(ST), 810(HW)^c, 811(ST), 812(ST)^c, 813(ST)^c, 814(EM), 815(EM), 816(EM), 817(EM), 818(EM), 819(EM)^c, 820(SA), 821(SA), 822(SA)^c, 823(HW), 824(HW).

NOVEMBER: 825(ST), 826(HY), 827(ST), 828(ST), 829(ST), 830(ST), 831(ST)^c, 832(CP), 833(CP), 834(CP), 835(CP)^c, 836(HY), 837(HY), 838(HY), 839(HY), 840(HY), 841(HY)^c.

DECEMBER: 842(SM), 843(SM)^c, 844(SU), 845(SU)^c, 846(SA), 847(SA), 848(SA)^c, 849(ST)^c, 850(ST), 851(ST), 852(ST), 853(ST), 854(CO), 855(CO), 856(CO)^c, 857(SU), 858(BD), 859(BD), 860(BD).

c. Discussion of several papers, grouped by Divisions.